

Diffractive Vector Meson Production with a Large Momentum Transfer

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Abstract. We summarise recent progress in the computation of helicity amplitudes for diffractive vector meson production at large momentum transfer and their comparison to data collected at the HERA collider.

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We are interested in the process illustrated in Figure 1 where a proton and photon collide at high centre-of-mass energy to produce a vector meson which is far in rapidity from the other final state particles. So that we can make use of QCD perturbation theory, we insist that the meson be produced at large transverse momentum. The HERA experiments have measured the meson p_T spectrum and spin density matrix elements for the ρ , ϕ and J/ψ mesons [1, 2]. There has also been considerable theoretical interest [3]–[12].

At first sight the data are puzzling. For light quarks one naively expects the meson to be predominantly longitudinally polarized and transversely polarized meson production to be suppressed by the current quark mass. This is not what is seen in the data: the meson is without doubt predominantly transversely polarized for both the ρ and ϕ mesons. This can be seen in Figure 2 which shows the measured spin density matrix elements for the ρ . The results for the ϕ are very similar to those for the ρ and we neglect to show them here. Writing the helicity amplitudes as $M_{\lambda_\gamma \lambda_V}$, r_{00}^{04} is proportional to $|M_{+0}|^2$, r_{10}^{04} measures the interference between M_{++} and M_{+0} , and r_{1-1}^{04} measures

the interference between M_{++} and M_{+-} . The challenge is to explain the largeness of r_{1-1}^{04} and the smallness of r_{00}^{04} .

Here we report specifically on the results presented in [10, 11]. The scattering is supposed to proceed by exchange of a pair of interacting reggeized gluons; corresponding to the sum of all leading logarithms $\sim (\alpha_s \ln(s/(-t)))^n$ where $-t = p_T^2$ and s is the Mandelstam variable for the hard subprocess. Being a leading logarithmic summation, the normalisation of the resulting amplitudes is not certain, nor is the correct way to treat the strong coupling α_s . Nevertheless, the leading logs do crucially include as a subset a sum of double logarithms which ensures that the dynamics are dominated by configurations where the two exchanged gluons share the momentum transfer. This is to be contrasted with the fixed order perturbation theory result which anticipates large contributions from asymmetric configurations where one gluon carries all of the momentum transfer. Summing the leading logarithms also has the virtue that the amplitude is finite even in the massless quark limit. This is not the case for fixed order perturbation theory which is plagued by divergences which arise from the end-points of the integration over the light-cone momentum fraction of the quark which forms the meson.

The production of the meson factorizes from the hard scattering and the relevant hadronic matrix elements are expanded on the light-cone, as in [13]. We expand all matrix elements to twist-3, i.e. next-to-leading twist. A similar factorization can be performed for the photon, to ensure a clean separation between long and short distances. We do not however follow this path and instead use the QED coupling of the photon to the quark and antiquark pair. The quark mass then sets the size of the chiral odd contributions and also cuts off the integrals at sufficiently large transverse separations. However, we re-iterate that all our amplitudes are finite even in the massless quark limit. In order to induce a large enough transverse contribution,

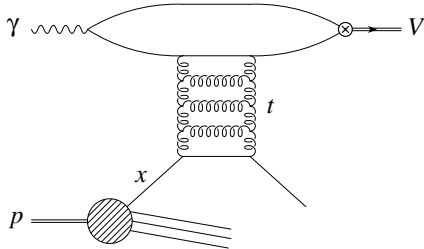


Fig. 1. Diffractive vector meson photoproduction at large momentum transfer.

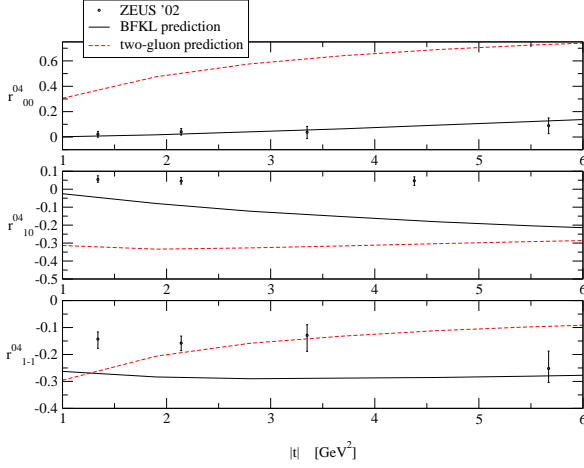


Fig. 2. ρ photoproduction: spin density matrix elements. Comparison of the two-gluon exchange prediction (fixed and running coupling) with BFKL exchange (fixed coupling).

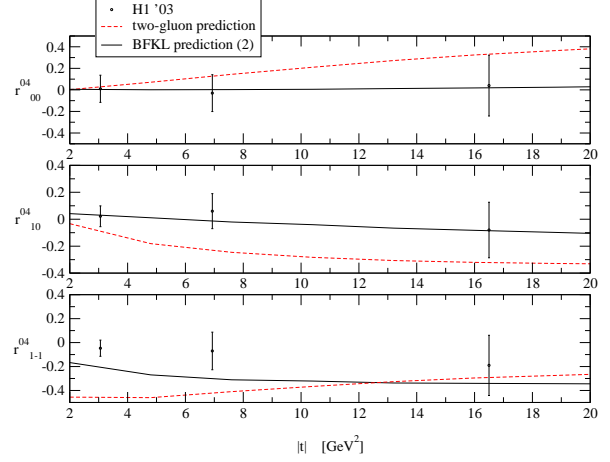


Fig. 4. J/ψ photoproduction: spin density matrix elements. Comparison of the two-gluon exchange prediction (fixed and running coupling) with BFKL exchange (fixed coupling).

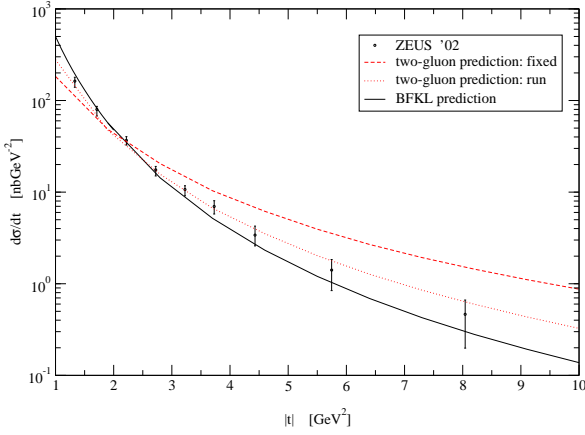


Fig. 3. ρ photoproduction: t -distribution. Comparison of the two-gluon exchange prediction (with fixed and running coupling) with BFKL exchange (fixed coupling).

we use the constituent rather than current quark mass in the hard scattering amplitude, i.e. we take $m = m_V/2$ where m_V is the meson mass. The results of the complete leading logarithmic summation are presented in Figures 2–5, where they are compared to the results obtained at lowest order in perturbation theory, i.e. corresponding to exchange of two gluons.

The two gluon exchange curves are shown for both constant α_s ($\alpha_s = 0.27$ for the ρ and $\alpha_s = 0.23$ for the J/ψ) and running α_s ($\alpha_s(1 \text{ GeV}) = 0.30$ for the ρ and $\alpha_s(1 \text{ GeV}) = 0.29$ for the J/ψ).¹ The BFKL (i.e. leading logarithmic) curves are determined using a fixed $\alpha_s =$

¹ The α_s dependence cancels in the spin density matrix elements.

0.17 in the coupling to the external particles and a fixed but different $\alpha_s = 0.25$ in the BFKL exponent. The same values are chosen for all mesons. One must also choose the scale Λ which enters the leading logarithms, i.e. $\ln(s/\Lambda^2)$. For all BFKL curves $\Lambda^2 = m_V^2 - t$. The two sets of BFKL curves labelled (1) and (2) correspond to slightly different meson tensor decay constants (this choice does not affect the spin density matrix elements). We refer to [11] for details on the meson wavefunction and on the effect of making different choices for the unknown parameters listed above. Our main conclusions do not depend upon these details.

We find that it is generally not too difficult to find a fit for the meson p_T spectra shown in Figures 3 and 5. Both BFKL and two-gluon exchange can describe the data with rather natural parameter values. The challenge is to simultaneously describe the data on the spin density matrix elements.

For light meson production, the two-gluon exchange results fail to predict the dominance of transverse meson production even using the constituent quark mass. The two-gluon exchange predictions are also plagued by the fact that the quark mass is an essential infrared regulator. In contrast, BFKL does anticipate predominantly transverse meson production and is infra-red finite. However we did not succeed in finding agreement between BFKL and the r_{10}^{04} matrix element – BFKL being too large and negative. The double helicity flip amplitude enters into r_{1-1}^{04} and vanishes at leading twist. Our next-to-leading twist calculation is therefore only leading order in this quantity. Using BFKL we tend to overestimate its magnitude. For the heavier J/ψ meson, BFKL is in very good agreement for both the p_T spectrum and the spin density matrix elements, although the data do have larger uncertainties than for the light mesons.

Looking in detail at the theoretical calculations, one finds that there are large contributions from the end-point

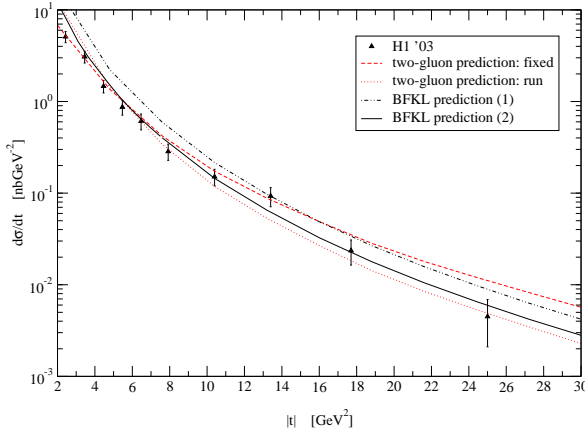


Fig. 5. J/ψ photoproduction: t -distribution. Comparison of the two-gluon exchange prediction (fixed and running coupling) with BFKL exchange (fixed coupling).

regions of the integral over the quark (and antiquark) light-cone momentum fractions. It is these regions which cause the two-gluon calculation to diverge, and even in the BFKL case there remain sizeable contributions. Large end-point contributions bring into question the validity of the factorization of the amplitude into a perturbative part and a non-perturbative meson matrix element and so should be a cause of concern. One can rather artificially suppress these contributions by raising the quark mass and it is noticeable that after so doing the agreement with the spin density matrix elements improves substantially. Hitherto, we have ignored the fact that there is a Sudakov suppression of radiation off the quark and antiquark since we are dealing with an exclusive quantity. We suggest that this suppression of radiation may diminish the contribution from the large dipoles which arise as one moves into the end-point region although it remains to quantify the effect.

In summary, the HERA data on diffractive meson production at high p_T are proving a real challenge to explain. Both fixed order and all order calculations can explain the p_T spectra of the mesons but neither can at present provide a satisfactory explanation of the helicity structure. There is room for improvement in the theoretical analyses whilst on the experimental side the goal must be to obtain data out to larger values of t for the light mesons, and to reduce the errors, especially for the J/ψ meson.

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References

1. S. Chekanov *et al.* [ZEUS Collaboration], *Eur. Phys. J.* **C26** (2003) 389.
2. A. Aktas *et al.* [H1 Collaboration], *Phys. Lett. B* **568** (2003) 205.
3. J. R. Forshaw and M. G. Ryskin, *Z. Phys.* **C68** (1995) 137.
4. J. Bartels, J. R. Forshaw, H. Lotter and M. Wüsthoff, *Phys. Lett.* **B375** (1996) 301.
5. D. Y. Ivanov, R. Kirschner, A. Schäfer and L. Szymanowski, *Phys. Lett.* **B478** (2000) 101; erratum-*ibid.* **B498** (2001) 295.
6. P. Hoyer, J. T. Lenaghan, K. Tuominen and C. Vogt, *arXiv:hep-ph/0210124*.
7. R. Enberg, L. Motyka and G. Poludniowski, *Eur. Phys. J.* **C26** (2002) 219.
8. J. R. Forshaw and G. Poludniowski, *Eur. Phys. J.* **C26** (2003) 411.
9. A. Ivanov and R. Kirschner, *Eur. Phys. J. C* **29** (2003) 353.
10. R. Enberg, J. R. Forshaw, L. Motyka and G. Poludniowski, *JHEP* **0309** (2003) 008.
11. G.G. Poludniowski, R. Enberg, J. R. Forshaw and L. Motyka, to appear in *JHEP*, *arXiv:hep-ph/0311017*.
12. A. Ivanov and R. Kirschner, e-Print Archive: *hep-ph/0311077*.
13. P. Ball, V. M. Braun, Y. Koike and K. Tanaka, *Nucl. Phys.* **B529** (1998) 323.
14. P. Ball and V. M. Braun, *Nucl. Phys.* **B543** (1999) 201.

